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# JOINT DETERMINATION OF INTERNAL ORGANIZATIONAL DESIGN: DECISION-MAKING, TASK ALLOCATION, AND INCENTIVE SCHEME

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# Joint Determination of Internal Organizational Design: Decision-Making, Task Allocation, and Incentive Scheme

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**Abstract:** This paper studies the issue of designing an optimal organizational form: design for sub-units' task allocation, decision-making structure, and incentive schemes for organizational members. Depending on the way tasks are allocated between the sub-units, and whether decision-making is centralized or not, organizations face a trade-off between coordination and information. Task allocation by production processes calls for coordination more strongly than the allocation by final products. Centralized decision-making serves for better coordination, whereas decentralization serves for better information. The coordinational benefit under centralization gets bigger as the organization's common uncertainty increases, and this benefit is magnified when the sub-units are functionally divided by production processes. The informational benefit under decentralization gets bigger as the organization's local uncertainty increases, and this benefit is magnified when the sub-units are designed autonomous. Thus, complementarily designed organizations tend to have centralized decision-making structures and fixed salary scheme, whereas less complementarily designed organizations tend to have decentralized decision-making and 'pay for performance' incentive contract.

# 1 Introduction

In designing an organization, a designer has to consider several basic internal structures of the organization, including what kind of and how much interaction be implemented among its sub-units, how much of decision-making power be delegated to them, and what kind of incentive schemes be provided for its members. These organizational design variables, say task allocation among sub-units, decision-making structure, and incentive scheme, usually differ across organizations, and often appear in specific combinations. For example, armies and government bureaucracies rely more on centralized control, and they design their subdivisions more or less complementary (that is, mutually supportive). Consider the relationship between the infantry unit and the artillery unit in an army and the relationship between the state department and the justice department in a government. The members in those organizations usually receive a fixed salary. On the other hand, investment banks and general hospitals rely more on decentralized delegation, and they design their subdivisions rather self-contained. In investment banks, the relationship is rather autonomous between foreign currency dealers and bond traders. Also autonomous is the relationship between the ENT department and the psychiatric department in a general hospital. In those organizations, several incentive schemes are often used other than a fixed salary. In most investment banks, for example, fund managers are usually rewarded according to the 'pay for performance' scheme.

Dependence of an organization's internal structures on its external environment has been widely reported by contingency theorists in management. The contingency theory postulates that an organization's internal structures and its members' behavioral patterns are to a great extent affected by its external conditions. Woodward (1958) reports that successful organizations in different industries are characterized by different internal structures. After analyzing the history of several pioneering firms, Chandler (1962) also concludes that organizational structures follow, and are guided by strategic decisions, which, in turn, must respond to environmental changes.

According to classical economic theories, economic agents' activities are most efficiently coordinated through the market mechanism. However, various market imperfections give rise to organizational coordination as an alternative. Among those imperfections, we especially emphasize on the fact that organizations are operating in uncertain environments and organizational members have bounded rationality. The organizational members are hierarchically arranged, differing in their decision-making authority and accessibility to various sources of information. Thus, two basic elements must be considered for better organizational performance. One is 'efficient information transmission', referring to how to convey each member's information to others, and the other is 'effective incentive provision', referring to how to align members' diverse interests with the organization's objectives. The internal structures of an organization ought to be chosen to maximize information flow and to minimize incentive distortion.

In this paper, we are interested in studying how an organization's external environments shape its internal structures. Thus, we ask why some organizations have more centralized decision-making structures than others, why some organizations ask their subordinates to specialize in a certain function (process), whereas others ask them to produce a certain final product, and why some organizational members are paid for their performance while others are paid a fixed salary. Especially, we are interested in seeing relationships among these organizational design variables.

We consider an organization which produces two final goods. Each good, to be produced, needs to go through two production lines. The organization is composed of a single top manager and two functionally interrelated subordinates. The top manager designs the organizational internal rules and structures, and monitors the subordinates' effort levels if necessary. He does not participate in production itself, though. The subordinates actively participate in production by providing efforts, guided by the organizational rules and incentives.

It is natural to assume that the top manager can determine the degree of interaction between the sub-units by choosing the way to allocate the subordinates. The top manager, by allocating the sub-units along the production lines (U-form organization), magnifies the degree of interaction. By allocating the sub-units along the final products (M-form organization), he reduces the degree of mutual dependence. In our model, the degree of interaction between the subordinates is captured through the extent that one subordinate's effort level helps the other's performance.

From a different perspective, the organization, by allocating its sub-units along the processes, makes each sub-unit specialize in a certain function and can exploit returns to scale, presumably arising from division of labor. But, by allocating its sub-units along the final products, it makes each sub-unit's task overlap with others and incurs waste of resources at the benefit of increased autonomy and the resulting flexibility.

There are various kinds of uncertainties the organization faces, common uncertainty, two line-specific uncertainties, and two good-specific uncertainties. The common uncertainty influences the entire organization, whereas each line-specific uncertainty only affects that particular production line and each good-specific uncertainty only affects that particular good. Due to the hierarchical arrangement, the top manager has privileged access to the common uncertainty, and the subordinates have privileged access to their own line-specific uncertainty when they are allocated along the production lines and to their own good-specific uncertainty when they are allocated along the goods.

To reduce the uncertainty the organization faces, information needs to be shared among the organizational members. In general, there are two kinds of information flows within the organization. One is top-down information flow and the other is bottom-up flow. In this paper, we only consider the first one. Due to the pyramid shape of the organization, the top-down information flow does not face traffic jamming, whereas the opposite flows face capacity constraints. To simplify, we assume that there is no jamming at all in the top-down information flow while there is extreme jamming in the opposite information flow.

After receiving a signal about the common uncertainty, the top manager conveys his information to the local subordinates (top-down information flow). The top manager can use either instruction or suggestion for communication, depending on the degree of hierarchical control he would like to impose. Under the instruction mode, the subordinates must fulfill the instruction without having flexibility to revise it. We call this mode centralization. Under the suggestion mode, the subordinates can revise the suggestion by incorporating their own local information which is either line-specific or good-specific depending on the organizational form . We call this mode decentralization.

There are trade-offs between centralized control and decentralized delegation. Centralization has coordinational advantage, blocking the subordinates' incentive distortion, whereas decentralization has informational advantage, utilizing the local information. From a different perspective, centralization incurs an information cost, while decentralization incurs an agency cost. The agency cost of decentralization depends on the incentive contracts for the local managers.

The coordinational advantage of centralization is large when the common turbulence is big and when the sub-units are designed along the production processes. To ensure that the sub-units follow the top manager's instruction, the top manager must monitor each unit's activity level. Thus, input monitoring and a fixed salary scheme are usually observed under centralization. As the size of common uncertainty increases, the organization tends to rely more on centralized control, design its sub-units along the production processes, and provide a fixed salary for its local managers.

The informational advantage of decentralization, is large when the local turbulence is big, whether line-specific or good-specific. Under delegation, observing each unit's activity level directly is meaningless, and incentive for each local manager must be given by an incentive contract contingent on his performance. Thus, output monitoring and incentive payment scheme are often observed under decentralization. In this paper, we only consider two kinds of incentive contracts which are two dominant contractual features in the real world: individual incentive contracts and group incentive contracts. Under the individual incentive contract, each subordinate's payoff depends only on his performance, whereas it depends on the team performance under the group incentive contract.

Decentralization with group incentive scheme hits a balance between the combination (centralization, fixed salary) and the combination (decentralization, individual incentive). In terms of agency cost, by making each sub-unit's salary contingent on their combined performance, it reduces the agency cost of the (decentralization, individual incentive) combination at the cost of creating a new, free-rider problem. In terms of information, by delegating the authority to finalize decisions, it utilizes the local information which is not available under the former combination.

We expect to derive that the organization tends to use centralized control if the common uncertainty is big and the local uncertainty is small, if the degree of interaction among the subordinates is high, and if the input monitoring cost is low. Moreover, the centralized organization provides fixed salary schemes for the subordinates and always organizes them according to the production line (i.e., U-form centralization). On the other hand, the organization tends to decentralize and use individual incentive contracts if the market uncertainty is small and the local uncertainty is big, and if the degree of interaction is low, whereas it tends to decentralize and use group incentives if both the market and local uncertainties are big. Decentralized delegation may come along with an M-form organizational mode (i.e., organizing the subordinates according to the good) if the good-specific uncertainty is sufficiently big compared with the line-specific uncertainty. These expected results look quite consistent with many empirical findings in the organizational literature.

There are several papers that study the organization's internal design issues. However, most of them address only one issue out of these inter-related design issues. For decision-making structure, Bolton and Farrel (1990) find, in the context of an entry game into a natural monopoly, that centralization is preferred to speed up the entrance decision, whereas decentralization is preferred to make use of potential entrants' private information. In comparing the relative efficiencies of centralized control and decentralization, Aoki (1986) argues that decentralized firms have an advantage in identifying and quickly responding to emergent events, while centralized firms have advantage in coordinating the operating units through the use of common technology. More recently, Aghion and Tirole (1997) show that delegating (formal) authority to the agent can facilitate the agent's participation in the organization and enhance the agent's incentive to acquire information about the project alternatives. At the same time, it can involve a costly loss of control since the agent may choose the project that is not best for the principal.

Regarding task allocation for organizational sub-units, Maskin, Qian, and Xu (1997) show that if the regional shocks are more closely correlated than the industrial shocks, an M-form organization is better than a U-form organization, and *vice versa*. It is because, when the regional shocks are more closely correlated than the industrial shocks, designing relative incentive contracts for regional operating managers is easier than designing relative contracts for industry-wise operating managers. Thus, an M-form organization enables the top management to design relative incentive contracts for the local managers that are less costly in the sense of Blackwell's efficiency. Aghion and Tirole (1995) show that a growing firm eventually switches from a U-form organizational mode to an M-form. As a firm grows, the headquarter's overload increases. To reduce the headquarter's overload, it is a good idea to create several profit centers.

However, none of the above papers study the interrelationship between the organization's decision-making structure and other internal design issues. One exception is Holmstrom and Milgrom (1994). Using a multi-task principal-agent model, they study the complementarities of various incentive instruments such as asset ownership, decision-making structure, and incentive contract. They show that, as the difficulty of evaluating performance and the importance of non-selling activities increase, firms tend to choose direct selling rather than using independent sales representatives. And that the in-house sales agents tend to face more restrictions for outside activities and to receive a fixed salary. However, they do not analyze the organizational design for sub-units' task allocation.

The rest of the paper is organized as follows. In section 2, we present a simple organizational model. In section 3, we investigate a hypothetical case in which the top manager commands perfect information on both the common shock and the local shocks. In sections 4 and 5, we derive the organization's expected profits under centralization and decentralization, respectively, assuming that the top manager has information only on the common shock. In section 6, by comparing the organization's expected profits under centralization and decentralization, we identify the main factors that determine the organization's optimal decision-making structure and its design for sub-units' task allocation. In section 7, we apply our results to explaining several stylized phenomena in organizations. Concluding remarks follow in section 8. All the proofs of the Lemmas and Propositions are deferred to the Appendix.

## 2 The Model

We view an organization as a collection of decision-makers with bounded rationality. Iin order for an organization to function effectively, information that each organizational member has must be fully utilized, and each organizational member's interest must be aligned to the organization's objectives. Accordingly, the organization's internal structures must be designed to minimize both information loss and incentive distortion.

For analytical simplicity, we consider an organization which produces two different goods, good $A$ and good $B$. Each good, to be produced, needs to go through two production lines, line 1 and line 2. One may think of line 1 as a production process which translates natural resources into intermediate goods, whereas line 2 as another production process which transforms those intermediate goods into final ones. Thus, there are four tasks that the organization must accomplish to produce both goods. They are denoted as $A1, A2, B1$, and $B2$, where $A1$ represents the task associated with the first production line for good $A$, and so on.

In performing those tasks, the organization faces with several kinds of uncertainties. We denote $\theta_m$ as a market shock which commonly affects the performances of all the tasks such as the government's economic policies. We denote $\theta_A$ (or $\theta_B$) as a good $A$ (or good $B$) specific shock which only affects the performances of the tasks associated with producing good $A$ (or good $B$), i.e., $A1$ and $A2$ (or $B1$ and $B2$). An example of this shock is change in consumers' taste for a good. Denote $\theta_1$ (or $\theta_2$) as a line 1 (or line 2) specific shock which only affects the performances of the tasks associated with line 1 (or line 2), i.e., $A1$ and $B1$ (or $A2$ and $B2$). An example of this shock is change in technology in a production line. All shocks are assumed to be mutually independent with zero means and variances equal to $\sigma_m^2$, $\sigma_A^2, \sigma_B^2, \sigma_1^2, \sigma_2^2$, respectively.

Organizations differ in assigning various tasks to their members. Some organizations emphasize more on each member's expertise in a certain function. The final products are produced by combining those specialized functions. An extreme organizational form toward this direction is a U-form organization according to Chandler's (1962) definition. Other organizations instead emphasize more on each member's general knowledge that helps him perform various functions and produce a certain product. An extreme organizational form toward this direction is an M-form organization according to Chandler's definition.

To model these features, we assume that the organization comprises of a top manager and two sub-units. The top manager is assumed risk-neutral. The two sub-units are run by two local managers who are also risk-neutral and have a reservation utility level of $\overline{U}$. Each local manager is supposed to perform two tasks. Thus, there are two reasonable ways the top manager assigns the above four tasks to two local managers. First, the sub-units are organized according to the production line, which resembles a U-form organization. In this case, the local manager 1 performs $A1$ and $B1$, while local manager 2 performs $A2$ and $B2$. Second, the sub-units are organized according to the good, which resembles an M-form organization. In this case, local manager A performs $A1$ and $A2$, while local manager B performs $B1$ and $B2$.[1] (Note that, when the sub-units are organized according to the production line, we denote the local managers as manager 1 and manager 2, whereas we denote them as manager $A$ and manager $B$ when they are organized according to the final product.)

To accomplish the assigned tasks, each manager $i$, $i = 1, 2$, or $A, B$, provides an effort, $a_i$, which costs him $c(a_i) = c_0 a_i$. Given manager $j$'s effort level, $a_j$, $j \neq i$, manager $i$'s effort $a_i$ contributes to the organization a unit value (average value per unit effort) $v_i$ which is denoted as

$$v_i = \mu - \frac{1}{2}a_i + \delta a_j + u_i, \; i \neq j \; i, j = 1, 2 \text{ or } A, B, \tag{1}$$

where $\delta$ denotes the degree of interaction between the two sub-units and $u_i$ denotes the uncertain factors involved.

The above equation indicates that the unit value of a local manager's effort decreases as his own effort level increases, reflecting diminishing marginal productivity of effort. In the above equation $\delta$ takes two values, $\delta_l$ and $\delta_g$, depending on the organizational form, where $\delta_l$ denotes the external effect between the two sub-units when they are organized according to the production line, and $\delta_g$ denotes the external effect when they are organized according to the good. We assume that $\delta_g \leq \delta_l$, implying the external effect is greater when they are organized according to production lines. For instance, in a university, the economics department and the physics department are

[1] One more possible task assignment is that one local manager performs $A1$ and $B2$, whereas the other local manager performs $A2$ and $B1$. However, since it is unreasonable in terms of specialization, we do not consider this case.

rather independent, whereas, in an army, the infantry unit and the artillery unit are mutually supportive in the sense that a good effort from the artillery unit improves the infantry unit's performance. Also, it is reasonable to assume that the maximum cross effect is smaller than the own effect, i.e., $0 < \delta_g \leq \delta_l < \frac{1}{2}$.

When the organization designs the sub-units according to the production line, the total amount of uncertainty involved with manager $i$'s effort becomes

$$u_i = \theta_m + \theta_i + \theta_A + \theta_B, \quad i = 1, 2. \tag{2}$$

It is because manager $i$ in charge of production line $i$ faces the market uncertainty and its own production line uncertainty, and because the manager performs two tasks $A_i$ and $B_i$.

On the other hand, when the organization designs its sub-units according to the good, the total amount of uncertainty involved with manager $i$'s effort becomes

$$u_i = \theta_m + \theta_i + \theta_1 + \theta_2, \quad i = A, B, \tag{3}$$

We assume that neither manager's unit value $v_i$ nor his effort level $a_i$ is directly observable to the top manager. However, the top manager can observe $(a_i, a_j), i, j = 1, 2$ or $A, B$, by investing $M$ into monitoring both managers' effort levels directly. On the other hand, there is a performance measure for unit $i$ such as unit $i$'s accounting sales value which is observable to the top manager without cost. We assume that unit $i$'s accounting sales value $x_i$ comprises of its true contribution, $v_i a_i$ and a white noise $\eta_i$,

$$x_i = v_i a_i + \eta_i, \;\; E(\eta_i) = 0, \;\; i = 1, 2 \text{ or } A, B. \tag{4}$$

The organization members have different access to different information sources. Due to hierarchical structure, it is quite natural to assume that the top manager has privileged access to the information about the market turbulence, while the local managers have privileged access to the information on their own local turbulence. Furthermore, since the area in which each local manager specializes varies with the organizational form, the local managers have access to different local information depending on how they are organized. For instance, if a local manager is designed to specialize in a certain production line, he has more information about the shock that is specific to that line, and if he is designed to specialize in a certain good, he has more information about the shock that is specific to that good. For simplicity, we assume that the top manager only observes the market shock, $\theta_m$, whereas local manager $i$ only observes his own specific local shock, $\theta_i$.[2] In other words, managers 1 and 2 observe $\theta_1$ and $\theta_2$, respectively, when the sub-units are organized according to the production line, whereas managers $A$ and $B$ observe $\theta_A$ and $\theta_B$, respectively, when the sub-units are organized according to the good.

After observing the true value of the market shock $\theta_m$, the top manager chooses each unit's effort level to maximize the whole organization's profit based on $\theta_m$. It is because the top manager's maximizing the organization's joint profit is equivalent to maximizing his own profit after giving each local manager the reservation level of utility. Let $a_i$ be the optimal effort level for unit $i$ as determined by the top manager, $i = 1, 2$ or $A, B$. Then, the top manager has to decide how to convey $a_i$ to sub-unit $i$. There are two ways for the top manager to communicate his decision $a_i$ with the sub-units. One is 'instruction' and the other is 'suggestion', differing in the degree of delegation. If $a_i$ is given as instruction, the sub-units have no other option but to carry out $a_i$ as instructed. We call this a centralized decision-making structure since the decision-making power lies with the top management. In this case, in order to ensure each unit to make the instructed level of effort, the top manager must invest $M$ to observe $a_i$, and design a forcing contract for each local manager $i$.

On the other hand, if $a_i$ is given as suggestion, manager $i$ can revise his effort level based on his own local information $\theta_i$. We call this a decentralized decision-

[2] So far as the top manager has more precise information on the market shock and less precise information on the local shocks than the local managers, the main implications in this paper still hold qualitatively.

making structure since the ultimate decision right is delegated to each local manager. Since the final effort level is determined by each local unit under decentralization, the top manager will have to design an incentive contract based on $(x_i, x_j)$ for each local manager rather than a forcing contract. Whether the sub-units will maximize the organization's profit or not in this case depends on how the local managers' compensation contracts are designed.

In sum, the top manager jointly determines the decision-making structure, the organizational form, and incentive contract for each local manager. When the organization is centralized, it cannot use the local managers' useful local information, incurring information loss. On the other hand, when the organization is decentralized, it cannot coordinate the local managers efficiently, incurring an agency cost. The amount of the agency cost depends on the organizational form as well as the local managers' incentive contracts. Thus, information and coordination are two basic elements to be considered in designing an optimal organization. To analyze this design problem, we adopt a backward induction. Given the organization's internal design (decision-making structure, organizational form, and incentive contracts for local managers), the top manager computes the organization's expected profit. Then, choose an optimal internal design to maximize the profit among all possible combinations of the decision-making structure, the organizational form, and the incentive contracts for local managers.

# 3 Full Information and Full Coordination

To mainly focus on the relative efficiencies of the two decision-making structures mentioned above, we start with a counterfactual benchmark case in which the top manager commands perfect information on all shocks and he fully coordinates the two sub-units (i.e., the top manager observes $a_i$ without cost). In this hypothetical case, the optimal decision-making structure must be a centralized one since the top manager knows everything.

First, suppose that the sub-units are organized according to the production line. As mentioned earlier, since the top manager's maximizing his own profit with guaranteeing the local managers the reservation level of utility, $\overline{U}$, is technically equivalent to his maximizing the organization's joint profit, the top manager's decision for both units' effort levels $(a_1^h, a_2^h)$ satisfies

$$(a_1^h, a_2^h) = \text{argmax}_{a_1,a_2}(v_1a_1 + v_2a_2) - c_0(a_1 + a_2). \tag{5}$$

From the first-order conditions, we have

$$\begin{aligned} a_1^h &= (R_1 + 2\delta_l R_2)/(1 - 4\delta_l^2), \\ a_2^h &= (R_2 + 2\delta_l R_1)/(1 - 4\delta_l^2), \end{aligned} \tag{6}$$

where $R_i = (\mu - c_0) + \theta_m + \theta_i + \theta_A + \theta_B,\ i = 1, 2$. We need $\delta < 1/2$ to satisfy the second-order condition. This condition states that, in determining unit $i$'s contribution to the organization, its own effort plays a bigger role than the other unit's effort.

This hypothetical situation will yield the maximum expected profit for the whole organization. Let $v_1^h$ and $v_2^h$ be the unit values corresponding to $a_1^h$ and $a_2^h$, that is, $v_i^h = \mu - a_i^h/2 + \delta_l a_j^h + \theta_m + \theta_i + \theta_A + \theta_B$, $i \neq j$, $i, j = 1, 2$. Thus, when the sub-units are organized according to the production line, the optimized expected profit under the hypothetical situation is

$$\begin{aligned} \pi_l^h &= E_{\mathcal{R}}[(v_1^h - c_0)a_1^h + (v_2^h - c_0)a_2^h] \\ &= E_{\mathcal{R}}[R_1(R_1 + 2\delta_l R_2) + R_2(R_2 + 2\delta_l R_1)]/2(1 - 4\delta_l^2), \end{aligned} \tag{7}$$

where $E_{\mathcal{R}}$ denotes that the expectation is taken with respect to $\mathcal{R} \equiv (\theta_m, \theta_1, \theta_2, \theta_A, \theta_B)$.

Using (1) and (2), we derive

$$\pi_l^h = \frac{1}{1 - 2\delta_l}[(\mu - c_0)^2 + \sigma_m^2 + \sigma_A^2 + \sigma_B^2] + \frac{1}{2(1 - 4\delta_l^2)}(\sigma_1^2 + \sigma_2^2). \tag{8}$$

Equation (8) shows that the organization's profit under the hypothetical situation increases with the size of any uncertainty. This is because, when the organization obtains full information about all kinds of uncertainties, the organization's expected profit increases with the amount of information on all kinds of uncertainties, and the amount of information on any uncertainty is measured by the corresponding variance because the unit value function is linear.

Likewise, one can easily derive that the optimized expected profit under the hypothetical situation when the sub-units are organized according to the good is

$$\pi_g^h = \frac{1}{1-2\delta_g}[(\mu - c_0)^2 + \sigma_m^2 + \sigma_1^2 + \sigma_2^2] + \frac{1}{2(1-4\delta_g^2)}(\sigma_A^2 + \sigma_B^2). \tag{9}$$

# 4 Centralization

We now turn to a realistic case in which the top manager has information only on the market shock. Suppose that the organization chooses centralization as its decision-making structure and the sub-units are organized according to the production line. Then, since the top manager's maximizing his own profit with guaranteeing the local managers the reservation level of utility, $\overline{U}$, is equivalent to his maximizing the organization's joint profit, the top manager chooses the optimal effort levels $(a_1^c, a_2^c)$ for both local units to maximize the expected joint profit based on his information $\theta_m$. That is,

$$(a_1^c, a_2^c) = \text{argmax}_{a_1,a_2}\ E_{\mathcal{R}}[(v_1 - c_0)a_1 + (v_2 - c_0)a_2|\theta_m], \tag{10}$$

where $E_{\mathcal{R}[\cdot|\theta_m]}$ denotes that the expectation is taken with respect to $\mathcal{R}$ given $\theta_m$ (similarly defined, hereafter). By solving the first-order conditions, we have

$$\begin{aligned} a_1^c &= (\gamma_1 + 2\delta_l\gamma_2)/(1-4\delta_l^2) \\ a_2^c &= (\gamma_2 + 2\delta_l\gamma_1)/(1-4\delta_l^2), \end{aligned} \tag{11}$$

where

$$\gamma_i = E_{\mathcal{R}}(R_i|\theta_m) = \mu - c_0 + \theta_m,\ i = 1, 2. \tag{12}$$

Under centralization, the top manager must invest $M$ to ensure that both sub-units carry out $a_i^c$ as instructed by the top manager, and design forcing contracts for both local managers. Thus, by plugging (11) into (10) and taking expectation with respect to $\theta_m$, we obtain the optimized expected profit under centralization when the sub-units are organized according to the production line as

$$\pi_l^c = \frac{1}{1-2\delta_l}[(\mu - c_0)^2 + \sigma_m^2] - M. \tag{13}$$

By subtracting (13) from (8), we have the cost of centralization compared with the hypothetical case when the sub-units are organized according to the production line as

$$\pi_l^h - \pi_l^c = \frac{1}{1-2\delta_l}(\sigma_A^2 + \sigma_B^2) + \frac{1}{2(1-4\delta_l^2)}(\sigma_1^2 + \sigma_2^2) + M. \tag{14}$$

The first two terms on the right-hand side of the above equation represent the efficiency loss of the centralized decision-making structure compared with the hypothetical case arising from the organization's inability to utilize information on the local shocks. Under the hypothetical case, every piece of information on $(\theta_1, \theta_2, \theta_A, \theta_B)$ is used cooperatively. Especially, when the sub-units are organized according to the production line, the good-specific information, $(\theta_A, \theta_B)$, is used commonly by both line managers, whereas the line-specific information, $(\theta_1, \theta_2)$, is used independently. However, under centralization, no local information is used at all. We term these as an information cost of U-form centralization. Obviously, the third term represents the monitoring cost that is necessary for implementing the forcing contracts for both local managers under centralization.

Likewise, one can easily derive the optimized expected profit under centralization when the sub-units are organized according to the good as

$$\pi_g^c = \frac{1}{1-2\delta_g}[(\mu - c_0)^2 + \sigma_m^2] - M, \tag{15}$$

and the cost of centralization compared with the hypothetical case in this case as

$$\pi_g^h - \pi_g^c = \frac{1}{1-2\delta_g}(\sigma_1^2 + \sigma_2^2) + \frac{1}{2(1-4\delta_g^2)}(\sigma_A^2 + \sigma_B^2) + M. \tag{16}$$

Since $\delta_g \leq \delta_l$, by comparing (13) and (15), we have

$$\pi_g^c \leq \pi_l^c, \tag{17}$$

implying that the sub-units must always be organized according to the production line under centralization. This is because only the market information is used under centralization regardless of the organizational form, and the organization will enjoy the maximum interaction effect when the sub-units are organized according to the production line because $\delta_g \leq \delta_l$.

This result under centralization is summarized in the following proposition.

**Proposition 1**: *Under centralization, to ensure that both sub-units choose $a_1^c$ and $a_2^c$ as instructed, the top manager designs forcing contracts for both local managers, and the sub-units are always organized according to the production line (U-form centralization).*

# 5 Decentralization

Suppose that the organization chooses a decentralized decision-making structure. Under decentralization, the top manager's decision on the optimal effort levels of both local managers based on his information, $\theta_m$, is the same as $(a_1^c, a_2^c)$ determined in equation (11) if the sub-units are organized according to the production line, and $(a_A^c, a_B^c)$ which is similar to $(a_1^c, a_2^c)$ if the sub-units are organized according to the good. However, he conveys $(a_i^c, a_j^c), i \neq j, i, j = 1, 2$ or $A, B$, to the sub-units as suggestion. Thus, after receiving $a_i^c$, each manager $i$ revises it based on his local information $\theta_i, i = 1, 2$ or $A, B$.

Since, given the top manager's decision rule, manager $i$ can always recover the top manager's information $\theta_m$ from his suggestion $a_i^c$, the information available to manager $i$ ultimately expands to $(\theta_m, \theta_i)$. However, this augmented information may not be used in an optimal way from the whole organization's perspective. In fact, local manager $i$ determines his final effort level, say $a_i^d$, by maximizing his own profit which is determined by his incentive contract.

Generally, the top manager has a limited ability in processing all the bottom-up information flows mainly due to his limited time and/or the headquarter's overload. Thus, to make our analysis simple, we assume that, although the local managers obtain private information on their own local shocks before choosing their effort levels, they cannot report their own information to the top manager. As a result, the top manager cannot design truth-telling contracts for both local managers.[3]

In this paper, we only consider two kinds of incentive contracts: an individual incentive contract, i.e., $s_i = s_i(x_i)$, and a group incentive contract, i.e., $s_i = s_i(x_i + x_j), i \neq j, i, j = 1, 2$, or $A, B$. These incentive contracts well cover the typical work practices in most organizations.[4] Although the organization's use of incentive schemes that are sensitive to individual performance measures has been considered as one of traditional work practices, the team-based group incentives recently receive growing attention in the literature as an alternative.[5]

Since the top manager and the local managers are assumed to be risk-neitral, without loss of any generality, one can only consider linear contracts. Thus, we denote the individual incentive contract for local manager $i$ as

$$s_i(x_i) = k_i x_i, ^{6},\ k_i \leq 1, i = 1, 2, \text{ or } A, B, \tag{18}$$

[3]Even if the top manager can design truth-telling contracts for local managers, our main results will not change qualitatively as long as the full information outcome is not obtainable. For some practical reasons why the top manager cannot design truth-telling contracts, see Laffont and Martimort (1997).

[4]For empirical evidence for the use of team-based group incentives, see Boning, Ichniowski, and Shaw (1997), and Ichniowski, Shaw, and Prennushi (1998).

[5]See Kandel and Lazear (1992), Baker, Gibbons, and Murphy (1994), Holmstrom and Milgrom (1994), and Milgrom and Roberts (1995).

[6]We do not need to consider a lump-sum transfer between the top manager and each local manager because the top manager's maximizing the joint profit is equivalent to maximizing his own profit with guaranteeing the local managers the reservation level of utility.

and the group incentive contract as

$$s_i(x_i+x_j) = h_i(x_i+x_j), 0 \le h_i \le 1, 0 \le h_i+h_j \le 1, i \ne j,\ i,j = 1,2,\ \text{or } A, B, \quad (19)$$

where $k_i$ and $h_i$ in the above two equations denote manager $i$'s incentive powers that are attached to his individual performance and the group performance, respectively.

The reason we specify in the above equation that $k_i \le 1$ and $h_i + h_j \le 1$ is because, if $k_i > 1$ or $h_i + h_j > 1$, then the top manager will actually try to minimize each sub-unit's accounting sales value (top manager's sabotaging activity). For example, if $k_i > 1$ in the individual incentive contract, the top manager's payoff will be negatively tied to the manager $i$'s accounting sales value. Thus, the top manager will face an incentive to exercise his sabotaging activity to reduce local manager $i$'s performance $x_i$. Likewise, if $h_i + h_j > 1$ in the group incentive contract, the top manager will have an incentive to exercise his sabotaging activity to reduce the joint performance $x_i + x_j$.

## 5.1 Decentralization with Individual Incentives

Suppose that the top manager designs individual incentive contracts, $s_i(x_i) = k_i x_i$ for both managers. We also start with the case in which the sub-units are organized according to the production line.

Since unit $j$'s local information is not revealed to unit $i$, unit $i$ has to form an expectation on unit $j$'s effort level based on its information $I_i \equiv \{\theta_m, \theta_i\}, i = 1, 2$. Here, unit $j$'s optimal effort level should be consistent with unit $i$'s expectation, and *vice versa*. To satisfy this requirement, we adopt a Bayesian Nash solution concept.

Thus, the top manager's optimization program in this case is:

$$\begin{aligned} &\underset{k_1, k_2}{Max} \quad E_{\theta_m}\{E_{\mathcal{R}}[(v_1 - c_0)a_1 + (v_2 - c_0)a_2|\theta_m]\} \\ &s.t. \\ &\quad (i)\ a_1 \in \text{argmax } E_Y[k_1 x_1 - c_0 a_1|I_1] \\ &\quad (ii)\ a_2 \in \text{argmax } E_Y[k_2 x_2 - c_0 a_2|I_2], \end{aligned}$$

where $Y \equiv \{\theta_m, \theta_1, \theta_2, \theta_A, \theta_B, \eta_1, \eta_2, \eta_A, \eta_B,\}$ denotes a set of all uncertainties in the model, and $I_i \equiv \{\theta_m, \theta_i\}$ is an information set available to manager $i$. The constraints in the above program denote local managers' incentive constraints.

Thus, given $(k_1, k_2)$, each unit's decision problem under decentralization is characterized by

$$\begin{aligned} a_1^d(k_1,k_2) &= \text{argmax}_{a_1} E_Y[k_1(v_1 a_1 + \eta_1) - c_0 a_1 | I_1], \\ a_2^d(k_1,k_2) &= \text{argmax}_{a_2} E_Y[k_2(v_2 a_2 + \eta_2) - c_0 a_2 | I_2]. \end{aligned} \tag{20}$$

By solving (20) as detailed in the appendix, we derive

$$\begin{aligned} a_1^d(k_1,k_2) &= \tfrac{1}{1-\delta_l}(\mu+\theta_m) + \theta_1 - \tfrac{1}{1-\delta_l^2}(\tfrac{c_0}{k_1} + \delta_l \tfrac{c_0}{k_2}) \\ a_2^d(k_1,k_2) &= \tfrac{1}{1-\delta_l}(\mu+\theta_m) + \theta_2 - \tfrac{1}{1-\delta_l^2}(\tfrac{c_0}{k_2} + \delta_l \tfrac{c_0}{k_1}). \end{aligned} \tag{21}$$

By plugging (21) into (1), we obtain the unit values for both local managers given $(k_1, k_2)$ as

$$\begin{aligned} v_1^d(k_1,k_2) = &\ \tfrac{1}{2(1-\delta_l)}(\mu+\theta_m) + \tfrac{\theta_1}{2} + \delta_l\theta_2 + \theta_A + \theta_B \\ &+[\tfrac{(1-2\delta_l^2)c_0}{2(1-\delta_l^2)k_1} - \tfrac{\delta_l c_0}{2(1-\delta_l^2)k_2}], \\ v_2^d(k_2,k_1) = &\ \tfrac{1}{2(1-\delta_l)}(\mu+\theta_m) + \tfrac{\theta_2}{2} + \delta_l\theta_1 + \theta_A + \theta_B \\ &+[\tfrac{(1-2\delta_l^2)c_0}{2(1-\delta_l^2)k_2} - \tfrac{\delta_l c_0}{2(1-\delta_l^2)k_1}]. \end{aligned} \tag{22}$$

Thus, as shown in the Appendix, given $(k_1, k_2)$, the expected profit in this case is

$$\begin{aligned} \pi_{lI}^d(k_1,k_2) = &\ \tfrac{1}{(1-\delta_l)^2}[(\mu-c_0)^2 + \sigma_m^2] + \tfrac{1}{2}(\sigma_1^2+\sigma_2^2) - \tfrac{(\mu-c_0)c_0}{(1-\delta_l)^2}(\tfrac{1-k_1}{k_1} + \tfrac{1-k_2}{k_2}) \\ &-\tfrac{(1-3\delta_l^2)c_0^2}{2(1-\delta_l^2)^2}[(\tfrac{1-k_1}{k_1})^2 + (\tfrac{1-k_2}{k_2})^2] + \tfrac{2\delta_l^3 c_0^2}{(1-\delta_l^2)^2}(\tfrac{1-k_1}{k_1})(\tfrac{1-k_2}{k_2}). \end{aligned} \tag{23}$$

From (23), we directly obtain the following lemma:

**Lemma 1**: *Let $k_i^d$ be the optimal incentive power of the individual incentive contract for local manager $i, i = 1, 2$, under decentralization. Then, $k_1^d = k_2^d = 1$, i.e., the organization must provide high-powered incentives for the local managers when it implements individual incentive contracts.*

From (21), we have

$$\frac{\partial a_i^d(k_i,k_j)}{\partial k_i} = \frac{c_0}{(1-\delta_l^2)k_i^2} > 0,$$

implying that as the local managers are provided with higher incentive, they increase their effort levels. If the incentive power is set equal to one, the local managers are induced to maximize their own profit which is different from maximizing the organization's joint profit due to the existence of the external effect. In fact, since $\delta_l > 0$, the effort level chosen by the self-interested local manager will be lower than the effort level that would be chosen by the joint profit maximizing manager with the same information $(\theta_m, \theta_i)$. Thus, the top manager would like to provide higher incentive to increase each sub-unit's effort level, if possible. However, it is not possible because, as discussed earlier, $k_i^d$ cannot exceed one. Therefore, the optimal incentive power given to each local manager, $k_i^d$, must be one, and there arises an efficiency loss due to lack of coordination under decentralization with individual incentives.

By plugging $k_1^d = k_2^d = 1$ into (23), we eventually derive that the optimized expected profit under decentralization with individual incentives when the sub-units are organized according to the production line is

$$\pi_{lI}^d = \frac{1}{(1-\delta_l)^2}[(\mu - c_0)^2 + \sigma_m^2] + \frac{1}{2}(\sigma_1^2 + \sigma_2^2). \tag{24}$$

By subtracting (24) from (8), we have

$$\begin{aligned}\pi_l^h - \pi_{lI}^d &= \tfrac{\delta_l^2}{(1-2\delta_l)(1-\delta_l)^2}[(\mu - c_0)^2 + \sigma_m^2] + \tfrac{1}{1-2\delta_l}(\sigma_A^2 + \sigma_B^2) \\ &\quad + \tfrac{4\delta_l^2}{2(1-4\delta_l)^2}(\sigma_1^2 + \sigma_2^2).\end{aligned} \tag{25}$$

As shown in (25), the cost of U-form decentralization with individual incentives compared with the hypothetical case is composed of three parts. Note that each local manager is maximizing his own profit rather than the organization's joint profit under decentralization with individual incentives. Thus, the first term on the right-hand side of (25) represents the cost that arises from that information on the market shock, $\theta_m$, is used non-cooperatively under decentralization with individual incentives. We term this as a cost of less coordination under decentralization with individual incentives, which increases with the size of the common shock. The second term represents the cost arising from that information on the good-specific shocks, $(\theta_A, \theta_B)$, is not used under decentralization when the sub-units are organized according to the production line, whereas the third term is the cost arising from that manager 1 only uses his own production line information, $\theta_1$, by taking expectation on $\theta_2$ and *vice versa*.

Likewise, one can easily derive the optimized expected profit under decentralization with individual incentives when the sub-units are organized according to the good as

$$\pi_{gI}^d = \frac{1}{(1-\delta_g)^2}[(\mu - c_0)^2 + \sigma_m^2] + \frac{1}{2}(\sigma_A^2 + \sigma_B^2). \tag{26}$$

The cost of M-form decentralization with individual incentives compared with the hypothetical case as

$$\begin{aligned} \pi_g^h - \pi_{gI}^d \; &= \tfrac{\delta_g^2}{(1-2\delta_g)(1-\delta_g)^2}[(\mu - c_0)^2 + \sigma_m^2] + \tfrac{1}{1-2\delta_g}(\sigma_1^2 + \sigma_2^2) \\ &+ \tfrac{4\delta_g^2}{2(1-4\delta_g)^2}(\sigma_A^2 + \sigma_B^2). \end{aligned} \tag{27}$$

## 5.2 Decentralization with Group Incentives

Now, suppose that the top manager designs group incentive contracts, $s_i(x_i + x_j) = h_i(x_i + x_j)$, for both managers. Again, we start with the case in which the sub-units are organized according to the production line. Thus, the top manager's optimization program in this case is:

$$\begin{aligned} &\underset{h_1, h_2 \quad s.t.}{Max} \quad E_{\theta_m}\{E_{\mathcal{R}}[(v_1 - c_0)a_1 + (v_2 - c_0)a_2|\theta_m]\} \\ &\qquad (i)\ a_1 \in \text{argmax } E_Y[h_1(x_1 + x_2) - c_0 a_1|I_1] \\ &\qquad (ii)\ a_2 \in \text{argmax } E_Y[h_2(x_1 + x_2) - c_0 a_2|I_2]. \end{aligned}$$

Given $(h_1, h_2)$, each unit's decision problem under decentralization in this case is characterized by

$$\begin{aligned} a_1^d(h_1,h_2) &= \text{argmax}_{a_1} E_Y[h_1(v_1a_1+v_2a_2+\eta_1+\eta_2)-c_0a_1|I_1], \\ a_2^d(h_2,h_1) &= \text{argmax}_{a_2} E_Y[h_2(v_1a_1+v_2a_2+\eta_1+\eta_2)-c_0a_2|I_2]. \end{aligned} \tag{28}$$

Thus, we similarly derive

$$\begin{aligned} a_1^d(h_1,h_2) &= \tfrac{1}{1-2\delta_l}(\mu+\theta_m)+\theta_1-\tfrac{1}{1-4\delta_l^2}(\tfrac{c_0}{h_1}+2\delta_l\tfrac{c_0}{h_2}) \\ a_2^d(h_2,h_1) &= \tfrac{1}{1-2\delta_l}(\mu+\theta_m)+\theta_2-\tfrac{1}{1-4\delta_l^2}(\tfrac{c_0}{h_2}+2\delta_l\tfrac{c_0}{h_1}). \end{aligned} \tag{29}$$

The expected profit given $(h_1, h_2)$ in this case is

$$\begin{aligned} \pi_{lG}^d(h_1,h_2) = \; & \tfrac{1}{1-2\delta_l}(\mu^2+\sigma_m^2)+\tfrac{1}{2}(\sigma_1^2+\sigma_2^2)-\tfrac{2}{1-2\delta_l}\mu c_0 \\ & +\tfrac{c_0^2}{2(1-4\delta_l^2)}[\tfrac{2(1+2\delta_l)}{h_1}-\tfrac{1}{h_1^2}+\tfrac{2(1+2\delta_l)}{h_2}-\tfrac{1}{h_2^2}-\tfrac{4\delta_l}{h_1h_2}] \end{aligned} \tag{30}$$

From (30), we obtain the following lemma:

**Lemma 2**: *When the organization implements group incentive contracts for the local managers under decentralization, the optimal incentive power on the joint sales value must be* $h_1^d = h_2^d = \frac{1}{2}$.

We now make the following assumption.

**Assumption 1**: $\mu > 2c_0$.

This assumption is needed to make $h_1^d = h_2^d = \frac{1}{2}$ a meaningful solution. Otherwise, $E_{\mathcal{R}}(a_1^d(h_1,h_2)) < 0$ and $E_{\mathcal{R}}(a_2^d(h_2,h_1)) < 0$, which implies that designing a group incentive contracts will never be optimal.

By substituting $h_1^d = h_2^d = \frac{1}{2}$, into (30), we derive that the optimized expected profit under decentralization with group incentives when the sub-units are organized according to the production line is

$$\pi_{lG}^d = \frac{1}{1-2\delta_l}[(\mu-c_0)^2+\sigma_m^2] - \frac{1}{1-2\delta_l}c_0^2 + \frac{1}{2}(\sigma_1^2+\sigma_2^2), \tag{31}$$

and by subtracting (31) from (8), we have

$$\pi_l^h - \pi_{lG}^d = \frac{1}{1-2\delta_l}c_0^2 + \frac{1}{1-2\delta_l}(\sigma_A^2+\sigma_B^2) + \frac{4\delta_l^2}{2(1-4\delta_l)^2}(\sigma_1^2+\sigma_2^2). \tag{32}$$

The cost of U-form decentralization with group incentives compared with the hypothetical case is also composed of three parts. Note that each local manager with a group incentive contract maximizes his profit that is positively tied to the organization's joint profit. Thus, unlike the case in which individual incentive contracts are designed, there is no coordination problem. However, there arises a new free-rider problem on each manager's side because $h_1^d = h_2^d = \frac{1}{2} < 1$. The first term in the right-hand side of (31) represents the cost arising from the free-rider problem. The second and third terms are the same as previously explained. Note that the cost of a free-rider problem is independent of the size of any uncertainty.

Likewise, one can easily derive the optimized expected profit under decentralization with group incentives when the sub-units are organized according to the good as

$$\pi_{gG}^d = \frac{1}{1-2\delta_g}[(\mu - c_0)^2 + \sigma_m^2] - \frac{1}{1-2\delta_g}c_0^2 + \frac{1}{2}(\sigma_A^2 + \sigma_B^2). \tag{33}$$

The cost of M-form decentralization with group incentives compared with the hypothetical case is

$$\pi_g^h - \pi_{gG}^d = \frac{1}{1-2\delta_g}c_0^2 + \frac{1}{1-2\delta_g}(\sigma_1^2 + \sigma_2^2) + \frac{4\delta_g^2}{2(1-4\delta_g)^2}(\sigma_A^2 + \sigma_B^2). \tag{34}$$

By comparing (24) with (26) and (31) with (33), we directly obtain the following proposition:

**Proposition 2**: *Under decentralization (using either individual incentives or group incentives), even if $\delta_g \leq \delta_l$, the sub-units may be organized according to the good (i.e., M-form decentralization) if $\delta_l - \delta_g$ is small and the size of good-specific uncertainties, $\sigma_A^2 + \sigma_B^2$, is sufficiently big compared with the size of line-specific uncertainties, $\sigma_1^2 + \sigma_2^2$. Otherwise, the sub-units will be organized according to the production line (i.e., U-form decentralization).*

As shown in Proposition 1, the sub-units will always be organized accoding to the production line under centralization (U-form centralization). However, under decentralization, different kinds of local information will be used depending on the organizational form. For example, line-specific information $(\theta_1, \theta_2)$ will be used regardless of incentive contracts when the sub-units are organized according to the production line, whereas the good-specific information, $(\theta_A, \theta_B)$, will be used when they are organized according to the good. Thus, if the value of information associated with the good-specific shocks, i.e., $\sigma_A^2 + \sigma_B^2$, is sufficiently bigger than that associated with the line-specific shocks, i.e., $\sigma_1^2 + \sigma_2^2$, then designing M-form decentralization (either with individual incentives or group incentives) will improve on the organizational efficiency compared with U-form decentralization.

Also, by comparing (24) with (31) and (26) with (33), we derive

$$\pi_{lI}^d - \pi_{lG}^d = \frac{1}{1-2\delta_l}c_0^2 - \frac{\delta_l^2}{(1-2\delta_l)(1-\delta_l)^2}[(\mu - c_0)^2 + \sigma_m^2], \tag{35}$$

and

$$\pi_{gI}^d - \pi_{gG}^d = \frac{1}{1-2\delta_g}c_0^2 - \frac{\delta_g^2}{(1-2\delta_g)(1-\delta_g)^2}[(\mu - c_0)^2 + \sigma_m^2]. \tag{36}$$

The first terms in the above two equations represent the cost of free-riding under decentralization using group incentives. The second terms represent the cost of less coordination under decentralization using individual incentives. From the above equations, we obtain the following lemma:

**Lemma 3**: *There always exists a unique $\hat{\delta} \in (0, \frac{1}{2})$ such that the group incentive contract is preferred to the individual incentive contract under U-form (or M-form) decentralization if and only if $\delta_l$(or $\delta_g$) $\geq \hat{\delta}$.*

Therefore, since $\delta_g \leq \delta_l$, we can directly obtain the following proposition from Lemma 3:

**Proposition 3**: *The group incentive contract is more likely to be designed under U-form decentralization than under M-form decentralization.*

Proposition 3 shows that group incentive contracts for local managers will be more likely when the sub-units are organized according to the production line than when they are organized according to the good. It is because if the group incentive contract is more efficient than the individual incentive contract under M-form decentralization, then it is always more efficient than the individual incentive contract under U-form decentralization. On the other hand, individual incentive contracts for local managers will be more likely when the sub-units are organized according to the good than when they are organized according to the production line.

# 6 Centralization vs. Decentralization

There is a trade-off between the centralized and decentralized decision-making structures. The decentralized decision-making structure is subject to incentive distortion either from less coordination when the individual incentive contracts are designed or from free-riding when the group incentive contracts are designed. On the other hand, the centralized decision-making structure is subject to information loss by not utilizing the local information. Thus, the answer to the question of which decision-making structure must be adopted and which incentive contract must be designed for each local manager, depends on the relative magnitude of the above three costs.

To simplify, let us assume that $\delta_g = \delta_l = \delta$. (Toward the end of this section, we will relax this assumption). Define

$$\sigma_{local}^2 = max\{\sigma_1^2 + \sigma_2^2, \sigma_A^2 + \sigma_B^2\}.$$

Then, the optimized expected profits under centralization, decentralization with individual incentives, and decentralization with group incentives reduce to, respectively:

$$\pi^c = \frac{1}{1-2\delta}[(\mu - c_0)^2 + \sigma_m^2] - M, \tag{37}$$

$$\pi_I^d \equiv max\{\pi_{lI}^d, \pi_{gI}^d\} = \frac{1}{(1-\delta)^2}[(\mu - c_0)^2 + \sigma_m^2] + \frac{1}{2}\sigma_{local}^2, \tag{38}$$

and

$$\pi_G^d \equiv max\{\pi_{lG}^d, \pi_{gG}^d\} = \frac{1}{1-2\delta}[(\mu - c_0)^2 + \sigma_m^2] - \frac{1}{1-2\delta}c_0^2 + \frac{1}{2}\sigma_{local}^2. \tag{39}$$

By subtracting (38) from (37), we obtain the benefit from centralization over decentralization using individual incentives as

$$P(\sigma_{local}^2, \sigma_m^2) \equiv \pi^c - \pi_I^d = \frac{\delta^2}{(1-2\delta)(1-\delta)^2}[(\mu - c_0)^2 + \sigma_m^2] - \frac{1}{2}\sigma_{local}^2 - M. \tag{40}$$

As shown earlier, the first term in the right-hand side of the above equation represents the cost of less coordination under decentralization with individual incentives arising from the fact that the sub-units are looking for a Nash solution rather than a team-efficient solution under decentralization with individual incentives. The second term represents the information cost of centralization arising from the fact that no local information is used under centralization. Obviously, the third term is the monitoring cost of centralization.

By subtracting (39) from (37), we obtain the benefit from centralization over decentralization using group incentives as

$$Q(\sigma_{local}^2, \sigma_m^2) \equiv \pi^c - \pi_G^d = \frac{1}{1-2\delta}c_0^2 - \frac{1}{2}\sigma_{local}^2 - M. \tag{41}$$

The first term represents the cost of free-riding under decentralization with group incentives, whereas the second and third terms are the same as above.

Also, by subtracting (39) from (38), we obtain the benefit from decentralization using individual incentives over that using group incentives as

$$T(\sigma_{local}^2, \sigma_m^2) \equiv \pi_I^d - \pi_G^d = \frac{1}{1-2\delta}c_0^2 - \frac{\delta^2}{(1-2\delta)(1-\delta)^2}[(\mu - c_0)^2 + \sigma_m^2]. \tag{42}$$

Finally, by drawing $P(\sigma_{local}^2, \sigma_m^2) = 0$, $Q(\sigma_{local}^2, \sigma_m^2) = 0$, and $T(\sigma_{local}^2, \sigma_m^2) = 0$ in $(\sigma_{local}^2, \sigma_m^2)$-space, we obtain Figure 1.

[Insert Figure 1 here]

From Figure 1, we obtain the following proposition:

**Proposition 4**:

*(1) If the local uncertainty is big and the market uncertainty is small, then the organization will be decentralized, and the local managers will be provided with high-powered individual incentive contracts.*

*(2) If both the local uncertainty and the market uncertainty are big, then the organization will be decentralized, and the local managers will be provided with group incentive contracts.*

*(3) If the local uncertainty is small and the market uncertainty is big, and/or if the monitoring cost is low, then the organization will be centralized, and the local managers will be provided with forcing contracts.*

Note that the information cost of centralization increases as the local uncertainty increases, that the cost of less coordination under decentralization using individual incentives increases as the market uncertainty increases, and that the cost of free-riding under decentralization using group incentives is independent of both uncertainties. Therefore, if the organization faces with a big market uncertainty along with a small local uncertainty, designing a centralized decision-making structure is optimal. However, if the organization faces with a small market uncertainty along with a big local uncertainty, then designing a decentralized decision-making structure with providing individual incentives is optimal. On the other hand, if both the market and local uncertainties are big, then designing a decentralized decision-making structure with providing group incentives is optimal.

Brickley and Dark (1987) found that most franchising companies, when deciding whether to franchise or not their units, are more likely to choose to franchise a unit as it is harder to monitor that unit (i.e., input monitoring). Also, Krueger (1991) reported that franchisees typically receive very high-powered incentives, while employed managers receive little or no explicit incentive pay. If we understand a company's choice between company ownership and franchising as a choice between centralized control and decentralized delegation, these empirical findings are quite consistent with the result reported in (3) of Proposition 4.

Regarding decentralization using group incentives, we would like to mention a recent paper by Ichniowski, Shaw, and Prennushi (1997). Ichniowski et. al., by investigating steel finishing processes in the U.S., concluded that the use of problem-solving team is more effective in improving worker productivity when it is adopted together with other work practices such as group incentives and flexible assignment of workers. In problem-solving teams, the members are usually empowered to make day-to-day decisions on project assignment and problem-solving (decentralization).

Also, from Figure 1, we can have the following proposition:

**Proposition 5**: *As the external effect among local managers gets bigger (i.e., $\delta$ gets closer to 1/2), the organization will be more likely to adopt centralization, while it will be more likely to adopt decentralization and to use individual incentives as the external effect gets smaller (i.e., $\delta$ gets closer to 0).*

From (40), (41), and (42), note that the cost of decentralization gets bigger as $\delta$ gets bigger, whether it is the cost of less coordination using individual incentives or the cost of free-riding using group incentives, and that the information cost of centralization remains constant regardless of the value of $\delta$. Also note that the cost of less coordination under decentralization with individual incentives approaches zero as $\delta$ goes close to zero, and that both the free-riding cost of decentralization using group incentives and the information cost of centralization remain substantial.

Anderson and Schmittlein (1984) and Anderson (1985) reported that the firms selling electronic components are more likely to choose to use independent sales agents as their true performances get more difficult to evaluate (i.e., output monitoring) and as their non-selling activities get more important, whereas they are more likely to choose to use in-house sales agents (i.e., employees) otherwise. Moreover, independent sales agents typically receive commission and work under little or no regulation, whereas the employed sales agents receive salary and work under the firms' strict regulations (such as work time, freedom of selling other companies' products, and buyers they can sell to). Note that $\delta$ in our model can be interpreted as the difficulty of evaluating each worker's true performance or the importance of non-selling activities. Therefore, our result in the above proposition is consistent with the empirical findings in Anderson and Schmittlein (1984) and Anderson (1985). It is also consistent with Aghion and Tirole's (1997) argument that decision rights tend to be delegated as the interests of subordinates and bosses get sufficiently correlated since $\delta$ can be explained as the degree of interest conflict between the top manager and the local managers.[7]

Up to now, we have assumed that $\delta_g = \delta_l = \delta$. Now, we return to our original assumption that $\delta_g \leq \delta_l$. Then, whether the organization adopts a U-form organizational mode or an M-form organizational mode depends on $\delta_l - \delta_g$ and the relative sizes of $\sigma_1^2 + \sigma_2^2$ and $\sigma_A^2 + \sigma_B^2$. Thus, as shown in Proposition 1, the organization always adopts a U-form organizational mode under centralization. However, as shown in Proposition 3, under decentralization, the organization will adopt an M-form organizational mode if $\sigma_A^2 + \sigma_B^2$ is sufficiently big compared with $\sigma_1^2 + \sigma_2^2$ and if $\delta_l - \delta_g$ is small, and *vice versa*.

[7] In a repeated setting in which delegation cannot be committed by a contract and only informal delegation is feasible through the top manager's reputation concern, Baker, Gibbons, and Murphy (1999) showed that informal delegation is infeasible when the subordinate's interests are too highly correlated with the boss's because the fallback is too attractive to the boss in this case. However, in this paper, we assume that formal delegation can be committed by a contract.

# 7 Applications

Here, we will consider two simple applications. These applications are not new. Neither, are they developed in full. Rather, they are taken to illustrate the implications of the model we have developed in this paper.

## 7.1 Environments and Organizations

As we already mentioned in the introduction, many contingency theorists observe several patterns regarding the relationship between organization's external environments and its internal structures.

One of the most common findings is that organizations in stable environments, compared with organizations under unstable environments, have more formalized structures (i.e., their decision-making practices are more centralized). For example, Lawrence and Lorsch (1968) reported that, in major plastic manufacturing firms in the U.S., the production department faced the least amount of uncertainty and was the most formally organized, the research department faced the largest amount of uncertainty and was least formally organized, and the sales department was in-between in terms of both external uncertainty and internal structures. The workers in the production department were usually organized as mutually supportive, whereas the sales agents were usually organized as rather autonomous.

The sales department's less predictable environments compared with that of the production department are mainly due to its large randomness at the local levels. We would like to quote from Lawrence and Lorsch's (1968) survey to emphasize the difference in the amount of uncertainty across sales and production departments. *On sales department:* "The market we sell to is broad and diverse. For example, in the toy business if the product (plastic materials) comes out in the right color at the right price, anybody will buy it, and anybody can make it. In contrast, for wire and cable customers, the right technology, service, and delivery are critical, and price is at the end of the line." *On production department:* "In production, life is really plain, as it is geared to running the kind of plant and equipment which they currently have and where most of the decisions are built in." Thus, as predicted from Proposition 4, the sales department relies more on decentralized delegation (less formality) and designs the workers rather autonomous, because its local uncertainty is big and typically specific to the business area in which each sales worker specializes, while the production department relies more on centralized control (more formality) and designs the workers complementary because its local uncertainty is small.

Another stylized phenomenon is that organizations, faced with emergency, tend to centralize their decisions. For example, centralized rationing is favored in warfare rather than the market system.[8] Also, Stiglitz (1989) said that the political decision-making process had to be centralized during war time. In warfare, what drastically increases is generally the randomness of the common shock for the whole economy. Thus, as predicted from Proposition 4, the economy as an organization must have a more centralized structure in the war time.

As stated in Proposition 4, the relative sizes of external uncertainties are important in determining the organization's internal structures.

## 7.2 The Dynamics of Organization

Blau and Meyer (1987), like many other sociologists, observe that as a bureaucracy grows, (i) the proportionate size of its administrative component gets smaller (flattening of bureaucracy), and (ii) authority over decisions is more likely delegated from the top management to lower levels (decentralization of bureaucracy). Although these findings seem to contradict the stereotypical view that a large bureaucracy is highly centralized and inflexible, they are well documented in the literature.[9] As proposed by Blau and Meyer, economies of scale in administration may explain the flattening

[8] See Milward (1977).

[9] See, for example, Williamson (1986).

trend in a bureaucracy. However, the decentralization trend is hard to explain by the same argument.

Similarly, Chandler (1962) found that a growing firm eventually switched from a U-form organizational mode to an M-form organizational mode.

When an organization is newly established, it generally faces a great deal of uncertainty mainly because it is newly introduced to the environment. As the organization develops over time, it accommodates itself to the environment, by internalizing the uncertainty into its structure, by making operation rules more routine and formal, and by defining duties and powers more precisely. Since common features of an organization are easier to internalize than idiosyncratic features and since the uncertainties associated with the production processes are easier to internalize than those associated with the products themselves, mature organizations seem to reduce more of common uncertainties than local uncertainties and more of line-specific uncertainties than good-specific uncertainties. As the relative magnitude of common uncertainty gets smaller, the organization will adopt a decentralized decision-making structure, and as the relative magnitude of line-specific uncertainty gets smaller, the organization will more likely take an M-form. Considering that less need for coordination under decentralization would demand a smaller size of the administrative component, our model also explains why bureaucracy shows the flattening trend as well as the decentralization trend. Along this line of argument, Williamson (1986, p.118) writes: "To the extent that uncertainty decreases as an industry matures (which is the usual case) the benefits that accrue to integration presumably decline. Accordingly, greater reliance on obligational market contracting is commonly feasible for transactions of recurrent trading in mature industries."

Such organizational dynamics may explain, to some extent, the changing pattern of Korea's development strategy as well.[10] The Korean government, at an early stage of economic development in the 1960s, used so-called 'mandatory planning', relying

[10]For details of Korea's development strategy, see Amsden (1989).

heavily on the government's coercive instructions rather than the market mechanism. However, around the 1980s, it began to switch to 'indicative planning', introducing rough guidelines with less coercion and delegating more economic decisions to the private sectors. Such a decentralization trend still continues even nowadays.

In the 1960s, Korea's economic infrastructure was poorly developed. The accounting, banking, and legal systems were yet to be developed. The capital market was not functioning effectively. Such lack of sound economic infrastructures contributed to magnifying common turbulence for the economy as a whole. Furthermore, the shortage of employment opportunities in the private sector made government jobs most attractive. Thus, the government was able to absorb the elite into its bureaucracy, resulting in the government's dominance over the private sectors in terms of information processing capacity. Consequently, at an early stage of development, a big macro uncertainty together with the government's dominance in informational ability made direct government interventions through mandatory planning more attractive than *laissez-faire*.

However, as the economy successfully grew, the lack of infrastructures was substantially ameliorated. In the meantime, the Korean society became more differentiated and sophisticated. This evolution has reduced the common uncertainty, while it has increased the local uncertainty. Also, rapid accumulation of know-how (including network) in the private sectors considerably undermined, and even reversed the government's dominance in information processing. These, in all, made economic decentralization and indicative planning more attractive at a later development stage in Korea around the 1980s, as predicted from Proposition 4.

The Korean economy should have moved further toward an autonomous structure from an initial central control mode. As the private sector becomes more diversified, the Korean government lacks in adequate knowledge needed to coordinate such a sophisticated economy well. This explains why, at a later stage of development, the Korean economy should have moved further toward the market system with less governmental interventions and less bureaucracy. However, the Korean economy has not been successful in restructuring its economy more toward the market system mainly due to strong resistance from various interest parties who were against such a move. This began to create inefficiency for the Korean economy as early as mid 1980s and resulted in serious economic crisis in the late 1990s.

The organizational theory developed in this paper also has useful implications for explaining Chinese 'success' vs. Soviet 'failure' in their transition from planned economies to market economies. When the transformation is under process at a massive level, it is mainly the randomness of common uncertainty which drastically increases. According to Proposition 4, the increase in common uncertainty calls for centralization, which is exactly opposite to the liberalization trend and leads to a dilemma.

Between the two countries, the shock arising from transition was much bigger for the former Soviet Union than for China. The former Soviet Union had a functionally divided economy. Each local republic was able to manage its economy only under the former Soviet block's coordination, whereas the Chinese provinces were rather autonomous even before the transition.[11] In the case of the former Soviet block, the additional common uncertainty results from unstable political situations, lack of confidence in money, high and uncertain inflation rates, and lack of central coordination. Accordingly, the dilemma was much larger for the former Soviet Union.

It is frequently argued that the establishment of well-functioning legal, banking, and accounting systems is a prerequisite for a successful, full-scale transformation.[12] This argument is consistent with our organizational theory since such establishment will reduce the common uncertainty, nullifying the demand for more centralization, and thus removing major obstacles to the liberalization movement. However, full

[11]See Qian and Xu (1993) for differences in initial conditions and reform policies between China and Eastern European countries.

[12]See, among others, Litwack (1991), McKinnon (1991, 1994), and Calvo and Frenkel (1991).

establishment of such systems will not be realized in a short period of time. In the meantime, these economies will be better operated by a centralized authority (decentralization through centralization) as is the case in China or in the earlier stage of the Korean development process. However, as Korea has already experienced, China's smooth and government driven transition will inevitably create many interest groups who will be against the move toward decentralization and competition in later stages. Thus, China's 'success' today can potentially cause a big problem in the future.

# 8 Concluding Remarks

This paper examines the issue of designing an optimal organizational form in terms of task allocation among sub-units, decision-making structure, and incentive schemes for organizational members. We view an organization as a collection of decision-makers at various hierarchical levels. Being bounded rational, the decision-makers have limited capacity to identify unstable environments that an organization faces. Efficient information flows and incentive alignments among the organizational members must be taken into account in designing an optimal organizational form.

By distinguishing the uncertainty an organization faces into two types, common uncertainty and local uncertainty, we clarify the relationship between the organization's internal structures and its external environments. Depending on the organization's design for task allocation, the internal impacts of the common and local uncertainties are differentially realized. The common uncertainty has a bigger internal impact on complementarily designed organizations, while the local uncertainty has a magnified impact on autonomously designed organizations. Also, the interaction between the sub-units gets stronger when tasks are functionally allocated along the production processes than when they are allocated along the final products.

Centralization serves for better coordination and decentralization serves for better information. The coordinational benefit under centralization increases as the randomness of the common uncertainty gets bigger, and this benefit is magnified when the organization designs its sub-units complementary. The informational benefit increases as the randomness of the local uncertainty gets bigger, and this benefit is magnified when the organization designs its sub-units rather autonomous. Thus, we derive a relationship between the organization's designs for task allocation and decision-making structure. That is, complementary organizations tend to adopt centralized decision-making and autonomous organizations tend to adopt decentralized decision-making.

The organization in our model is assumed to make only one kind of decision. In reality, however, most organizations make many different kinds of decisions, ranging from strategic decisions such as long term investments to operating decisions like daily productions. Different decisions involve different kinds of uncertainties. For most strategic decisions, the common uncertainty outweighs the localized uncertainty, whereas the opposite is the case for most operating decisions. Our model explains why most strategic decisions are made by the top management with the help of specialized staff members and why most operating decisions are made by the operating units rather autonomously. Our model also explains why, during war time, most strategic decisions are handled by a commanding center, while most tactic decisions are delegated to combat units.

Our model set-up is partly motivated by many differences between U-form organizations and M-form organizations. In a U-form organization, there exists a strong interrelation among different divisions. The nature of this interaction is often complementary. In U-form organizations, the common uncertainty is more important. On the other hand, in an M-form organization, different divisions are operating in geographically separated areas or are targeting differentiated markets. Each division's operation is rather autonomous. The common uncertainty is less important and the interaction among the divisions is weak.

We close this section by pointing out two limitations of this paper. First, this paper does not address other closely related organizational issues such as why most organizations are hierarchically designed, and what determines the span of control.[13] Second, in this paper, we only consider top-down information flow among the organizational members. In reality, however, there are bottom-up information flows as well. We believe that incorporating the bottom-up information flows into the model will be useful.

## APPENDIX

**Derivation of Equation (21):**

From the first-order conditions of the optimization problem (20) in the text, we derive

$$\begin{aligned} a_1^d(k_1,k_2) &= \mu - \tfrac{c_0}{k_1} + \theta_m + \theta_1 + \delta_l E_Y[a_2^d(k_2,k_1)|\theta_m,\theta_1], \\ a_2^d(k_2,k_1) &= \mu - \tfrac{c_0}{k_2} + \theta_m + \theta_2 + \delta_l E_Y[a_1^d(k_1,k_2)|\theta_m,\theta_2]. \end{aligned} \tag{43}$$

From (43), by plugging the second equation into the first and by using the fact that a repeated conditional expectation is equivalent to a single expectation conditional upon the least common information, we obtain

$$a_1^d(k_1,k_2) = \mu - \frac{c_0}{k_1} + \theta_m + \theta_1 + \delta_l(\mu - \frac{c_0}{k_2} + \theta_m) + \delta_l^2 E_Y E[a_1^d(k_1,k_2)|\theta_m]. \tag{44}$$

By taking a conditional expectation given $\theta_m$ on both sides of (44), we obtain

$$E_Y[a_1^d(k_1,k_2)|\theta_m] = \frac{1}{1-\delta_l}(\mu+\theta_m) - \frac{1}{1-\delta_l^2}(\frac{c_0}{k_1} + \delta_l\frac{c_0}{k_2}). \tag{45}$$

Thus, by plugging (45) into (44), we derive

$$a_1^d(k_1,k_2) = \frac{1}{1-\delta_l}(\mu+\theta_m) + \theta_1 - \frac{1}{1-\delta_l^2}(\frac{c_0}{k_1} + \delta_l\frac{c_0}{k_2}).$$

[13]Williamson (1967), Calvo and Wellisz (1978), and Qian (1994) consider these issues from an incentive perspective. Marschak and Radner (1972), Radner (1992,1993), and Geanakoplos and Milgrom (1991) consider the same issues from an information perspective.

And, likewise, we derive

$$a_2^d(k_2,k_1)=\frac{1}{1-\delta_l}(\mu+\theta_m)+\theta_2-\frac{1}{1-\delta_l^2}(\frac{c_0}{k_2}+\delta_l\frac{c_0}{k_1}).$$

▮

**Derivation of Equation (23)**: We can rewrite (21) as

$$\begin{aligned} a_1^d(k_1,k_2) &= \tfrac{1}{1-\delta_l}(\mu-c_0+\theta_m)+\theta_1-\tfrac{c_0}{1-\delta_l^2}(\tfrac{1-k_1}{k_1}+\delta_l\tfrac{1-k_2}{k_2}),\\ a_2^d(k_2,k_1) &= \tfrac{1}{1-\delta_l}(\mu-c_0+\theta_m)+\theta_2-\tfrac{c_0}{1-\delta_l^2}(\tfrac{1-k_2}{k_2}+\delta_l\tfrac{1-k_1}{k_1}). \end{aligned} \tag{46}$$

Also, using (22), we have

$$\begin{aligned} v_1^d(k_1,k_2) &= \tfrac{1}{2(1-\delta_l)}(\mu-c_0+\theta_m)+\tfrac{\theta_1}{2}+\delta_l\theta_2+\theta_A+\theta_B+\tfrac{c_0}{2(1-\delta_l^2)}[(1-2\delta_l^2)(\tfrac{1-k_1}{k_1})-\delta_l(\tfrac{1-k_2}{k_2})],\\ v_2^d(k_2,k_1) &= \tfrac{1}{2(1-\delta_l)}(\mu-c_0+\theta_m)+\tfrac{\theta_2}{2}+\delta_l\theta_1+\theta_A+\theta_B+\tfrac{c_0}{2(1-\delta_l^2)}[(1-2\delta_l^2)(\tfrac{1-k_2}{k_2})-\delta_l(\tfrac{1-k_1}{k_1})]. \end{aligned} \tag{47}$$

Therefore, by using (46) and (47), we derive

$$\begin{aligned} \pi_{lI}^d(k_1,k_2) &= E_{\theta_m}\{E_{\mathcal{R}}[(v_1^d-c_0)a_1^d+(v_2^d-c_0)a_2^d|\theta_m]\}\\ &= \tfrac{1}{(1-\delta_l)^2}[(\mu-c_0)^2+\sigma_m^2]+\tfrac{1}{2}(\sigma_1^2+\sigma_2^2)-\tfrac{(\mu-c_0)c_0}{(1-\delta_l)^2}(\tfrac{1-k_1}{k_1}+\tfrac{1-k_2}{k_2})\\ &\quad -\tfrac{(1-3\delta_l^2)c_0^2}{2(1-\delta_l^2)^2}[(\tfrac{1-k_1}{k_1})^2+(\tfrac{1-k_2}{k_2})^2]\tfrac{2\delta_l^3c_0^2}{(1-\delta_l^2)^2}(\tfrac{1-k_1}{k_1})(\tfrac{1-k_2}{k_2}). \end{aligned}$$

▮

**Proof of Lemma 1:**

From (23), given $k_2$, we obtain

$$\frac{\partial\pi_{lI}^d(k_1,k_2)}{\partial k_1}=\frac{c_0}{k_1^2(1-\delta_l)^2}[\mu-c_0-\frac{2\delta_l^3c_0}{(1+\delta_l)^2}\frac{1-k_2}{k_2}]+\frac{1-k_1}{k_1^3}\frac{(1-3\delta_l^2)c_0^2}{(1-\delta_l^2)^2}.$$

Since, from (46), we see that $(k_1,k_2)$ must satisfy that

$$\mu-c_0\geq\frac{c_0}{1+\delta_l}(\frac{1-k_1}{k_1}+\delta_l\frac{1-k_2}{k_2})\geq\frac{\delta_lc_0}{1+\delta_l}\frac{1-k_2}{k_2}.$$

Otherwise, we have that $E_{\mathcal{R}}[a_1^d(k_1,k_2)]<0$, which is obviously not optimal. Since $0\leq\delta_l\leq\frac{1}{2}$, we have

$$\mu-c_0\geq\frac{\delta_lc_0}{1+\delta_l}\frac{1-k_2}{k_2}\geq\frac{2\delta_l^3c_0}{(1+\delta_l)^2}\frac{1-k_2}{k_2},$$

and

$$\frac{1-3\delta_l^2}{(1-\delta_l^2)^2} > 0.$$

Therefore, we finally derive

$$\frac{\partial \pi_{lI}^d(k_1,k_2)}{\partial k_1} > 0, \quad \forall k_1 \in [0,1] \ \text{ for any given } \ k_2 \in [0,1].$$

As a result, we have $k_1^d = 1$, and by the same method, we have $k_2^d = 1$. ∎

**Proof of Lemma 2**: By taking a first derivative of $\pi_{lG}^d(h_1,h_2)$ in (30) with respect to $h_1$ given $h_2$, we have

$$\frac{\partial \pi_{lG}^d(h_1,h_2)}{\partial h_1} = \frac{1}{h_1^3 h_2}[2h_2 + 4\delta_l h_1 - (2+4\delta_l)h_1 h_2].$$

Since $0 \le h_1, h_2 \le 1$, we obtain

$$\frac{\partial \pi_{lG}^d(h_1,h_2)}{\partial h_1} > 0, \ \forall h_1 \in [0, 1-h_2] \ \text{ for any given } \ h_2 \in [0,1].$$

Thus, since $h_1 + h_2 \le 1$, we have $h_1 + h_2 = 1$. By plugging $h_2 = 1 - h_1$ into (30), we derive

$$\begin{aligned} \pi_{lG}^d(h_1) = \ & \tfrac{1}{1-2\delta_l}(\mu^2+\sigma_m^2) + \tfrac{1}{2}(\sigma_1^2+\sigma_2^2) - \tfrac{1}{1-2\delta_l}\mu c_0 \\ & + \tfrac{c_0^2}{2(1-4\delta_l^2)}[\tfrac{2}{h_1(1-h_1)} - \tfrac{1}{h_1^2} - \tfrac{1}{(1-h_1)^2}], \end{aligned}$$

which will be maximized at $h_1 = \frac{1}{2}$. Thus, we derive that the optimal incentive power for the group incentive contracts is $h_1^d = h_2^d = \frac{1}{2}$. ∎

**Proof of Lemma 3**:

Let $\phi(\delta) \equiv \frac{\delta^2}{(1-\delta)^2}$. Then, we have $\phi(\delta)$ is increasing in $0 \le \delta \le \frac{1}{2}$ with $\phi(0) = 0$ and $\phi(\frac{1}{2}) = 1$. Since $\mu > 2c_0$, we have

$$\frac{c_0^2}{(\mu-c_0)^2+\sigma_m^2} < 1.$$

Therefore, there always exists $\hat{\delta} \in (0, \frac{1}{2})$ satisfying

$$\phi(\hat{\delta}_l) = \frac{c_0^2}{(\mu-c_0)^2+\sigma_m^2}.$$

Since $\phi(\delta)$ is increasing in $\delta$, from (35) and (36), we can easily prove that $\pi_{lG}^d \ge (<) \pi_{lI}^d$ if $\delta_l \ge (<) \hat{\delta}$, and $\pi_{gG}^d \ge (<) \pi_{gI}^d$ if $\delta_g \ge (<) \hat{\delta}$. ∎

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